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ROLE OF WEAR RESISTANCE COATING PARAMETERS ON MAGNESIUM ALLOYS- A REVIEW

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ABSTRACT

In this review paper, various techniques involved in improvement of wear resistance of composite coated magnesium and its alloy are studied. The tribological analysis were performed by numerous authors on the composite coated Mg as a function of reinforcement content (wt. %), sliding speed (m/s), applied load (N) and sliding distance (m) were studied. The intensified properties were obtained from various particulates reinforcement, which are distinct in their aspect ratio are coated with base metal to provide good bonding strength between them. It also highlights the different manufacturing techniques have optimum control parameters required for strengthening mechanisms to obtain the intensified properties. The volumetric wear loss testing parameters are discussed and critical point for each specific Strengthening mechanisms is compared. The related proof to justify Archad relation of the increment of hardness decreases the wear rate. The increment of wear resistance and its effects on mechanical properties are discussed in this paper.

***KEYWORDS:** Magnesium Alloy, Wear Resistance, Composite Coating, Coating Techniques & Strengthening Mechanisms*

A REVIEW

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INTRODUCTION

Recent scrutiny in Magnesium and its alloys, which were applicable for the commercial purposes such as power tools, aviation, automobile industries and energy conservation, demands are increasing because of their low density approximately two-third of that of aluminium and high specific strength, as compared to other structural metals. Magnesium is the lightest material and it is 35% lighter than aluminium [1]. Mg or Mg alloy posses very poor wear resistance attributable to their softness. From the practical point of view, the increased resistance of magnesium alloys to abrasive wear is important in systems where they work in sliding motion, e.g. brake systems, engine elements (pistons and cylinders) and during processing, e.g. rolling or forging. Wear condition arises when there is relative motion between two solids under influence of the load, the motion can either sliding or rolling i.e. unidirectional or there are chances of combination of both rolling and sliding and also along with movement of oscillation at a small amplitude. Wear cannot be told as a material quality, but nevertheless it is a system reply. The term wear is coined as the loss of material from the surface of a hard substrate by means of frictional motion against a counter body due to some mechanical reasons. The loss of the material or the wear rate can be varied from 10^{-3} to 10^{-20} depending on the certain situation like sliding velocity, speed, load, type of the materials used,

and also the condition of the environment in which the wear test is conducted. The wear loss is occurred when the function of the tribosystem is no longer safeguarded, and it is in the form of microcracks or localized plastic deformation. Apart from bulk modification, several surface treatment processes including formation of composite layers have been applied to magnesium alloys, to improve their mechanical properties and enhance their wear resistance [2-8]. When the working environments of Mg or Mg alloys at enormously high temperature and working for long time duration are not suitable for using any lubricants, hence better option to make use of scratchy resistant coatings over the surface. The desired properties can be achieved by a judicious selection of the type and size of the reinforcing particles. The reinforcements should be stable in the given working temperature and also non-reactive too. The wear resistance of Composite coated magnesium mainly depends on two factors, size and volume fraction of the reinforcing phase [9]. In composite coating of Mg, the reinforcement particles such as Silicon Carbide, Aluminium Oxide, Titanium Carbide, Graphite, Boron carbide etc were predominantly used. The key role of reinforcement particle is to increase ultimate tensile strength, yield strength, hardness, ductility and wear resistance of Mg and its alloys [8]. The homogeneity in mixture of reinforcement particles helps in to sustain the maximum load applied under the test condition [10]. The particle distribution plays a significant role in the mechanical properties of the Magnesium Composite coating, which is improved by intensive shearing. However, Particulate reinforced composite coating on magnesium could be produced by many different methods, such as electrodeposition technique, thermal spray technique, laser melting technique, high velocity oxygen fuel technique, physical vapour deposition. Some of the commonly and available procedures that are used to conduct wear test are pin on disc, pin into bushing, pin on flat, rectangular flats on rotating cylinders, pin on cylinder used based on the desired application which are to be tested. This paper examines the various factors like (a) effect of various reinforcement (b) tribiology properties like volumetric wear loss (c) processing technique and its effects. (d) Comparison of composite coating parameters for various techniques on magnesium alloys was discussed.

PLASMA ELECTROLYTIC OXIDATION

Plasma electrolytic oxidation (PEO) is an electrochemical surface treatment process for generating oxide coatings on metals which is similar to anodizing. A thick growth of oxide layer is employed on the surface of the substrate by applying higher potentials discharges resulting plasma. Resulting localized plasma generated by dielectric breakdown reactions has high temperature and pressure which modify the growing oxide layer. Processes include melting, melt-flow, re-solidification, sintering and densification of the growing oxide.

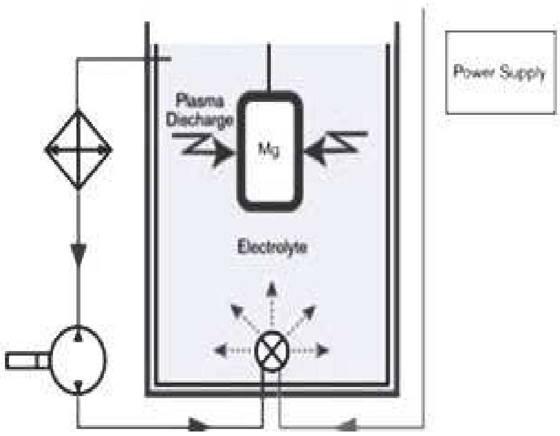

Figure 1: Schematic Illustration of Peo Process

Srinivasan et al. obtained two coatings with MgO and ZrO_2 as main constituents using phosphate and fluorozirconate containing electrolytes, respectively. A constant voltage of 420V was applied. Similarly, the coating produced in the phosphate electrolyte (with thickness of 30 m) was resistant against the 2 N load in sliding wear test; yet, it failed under 5N load as its load-bearing ability was low. Coating thickness depends on time period of electric current supplied. Due to three-body abrasive wearing in the wear track that is caused by crushed ceramic particles, the phosphate coating had a wear rate higher than the substrate alloy. The coating created in the acidic electrolyte containing K_2ZrF_6 was seen to possess a sponge-like structure with a worse behavior compared with the bare underlying substrate under 2 and 5N loadings. Hence, it was not recommended for direct application in case of tribological properties improvement [11].

Jun DING et al introduced sodium tungstate to electrolyte, found useful for improving tribological properties. Increasing Na_2WO_4 concentration up to 6 g.lit−1 in electrolytes that contained silicate and KOH during PEO-treatment of AM60B alloy led to increase in porosity. It was observed that microhardness and wear rate increased from 510Hv and 3.55 $\times 10^5$ mm^3 N^{-1}m^{-1}, in the base electrolyte, to 710Hv and 2.54 $\times 10^5$ mm3. N^{-1}m^{-1}, in the base electrolyte with 6 g.lit−1 Na_2WO_4. Hardness improvement and reduction of wear rate could be explained by increase in content of hard Mg_2SiO_4 in the coating corresponding with addition of sodium tungstate [12].

M. J. Shen et al studiedAFM micrographs of PEO coatings on AZ31 magnesium alloy, showed that addition of 3 mg.lit^{-1} borax (Na_2B4O_7) to the base electrolyte containing 10 g.lit^{-1} sodium silicate and 4 g.lit^{-1} potassium hydroxide caused reduction of surface roughness by about 50 percent. This was stated to be due to change of sparking characteristics during the process. EDS and XPS analyses revealed that boron contributed to the deposition process. XRD analysis proved that amorphous boron existed in the coating. Microhardness and density of PEO coating improves with addition of boron. According to results of reciprocal wear test, wear rate of the underlying magnesium alloy (uncoated) was 86.83 $\times 10^{-4}$ mm^3 N^{-1}m^{-1}. However, it was 20.96 mm^3 N^{-1}m^{-1} and 6.69 mm^3 N^{-1}m^{-1} in borax-free and borax-bearing coatings, respectively. Therefore, it may be deduced that addition of borax can significantly affect wear rate reduction in the coatings [13].

M.Asgari et al studied the outcome of stirring rate and concentration percentage of alumina nanoparticles in composite coated AZ31 magnesium alloy by plasma electrolytic oxidation. At higher stirring rates, the absorption level of alumina nanoparticles is decreased because, the nanoparticles are washed from the anode surface by high turbulence current. It is found that at stirring rate of 100 rpm the level of nanoparticles deposition is higher. Also by increasing the concentration of alumina nanoparticles in the electrolyte to 30g/L decrease the porosity in the coating at 100 rpm lead to the best corrosion resistance in the coating and lowest wear rate [14].

ELECTROLESS PLATING PROCESS

Electroless plating is an auto-catalytic chemical technique, used to deposit a layer of hybrid materials on a solid work piece in the presence of a reducing agent. The reducing agent reacts with the metal ions present in the electrolyte to deposit on the substrate metal.

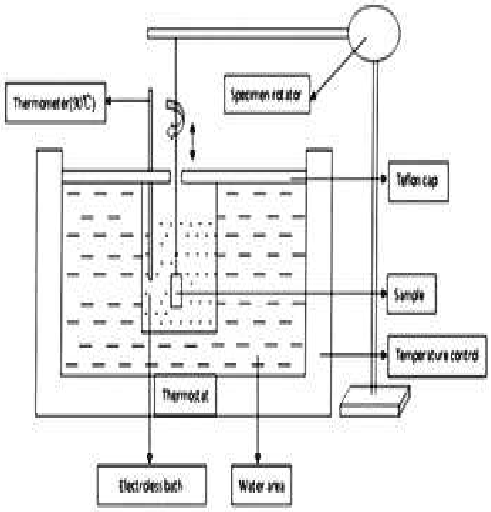

Figure 2: Schematic Illustration Electroless Plating Process

E. Correa et al reported that the wear test results of electroless Ni–B coated magnesium and AZ91D alloy are relatively 2 times lesser on pure Mg and AZ91D Mg alloy. Etching of the substrates develops a thicker oxide layer on the magnesium than on the alloy. Both the substrates treated at nickel plating bath times of 15, 30 or 60 s, with boron incorporated in electroless nickel plating bath into the layers. Wear rates obtained for applied force 6N and Sliding velocity (0.014 m/s). Both the Ni–B coated magnesium and AZ91D alloy show signification reduction in wear rates. An oxide/hydroxide layer is formed on the surface with the combination of alumina-grit blasting and alkaline etching of the substrates, with enrichment of zinc is responsible for the enhancement of wear resistance [15].

Li Guangyu et al developed a technology for electroless Ni-P deposition using a low cost sulfate nickel plating bath on AZ91D Mg alloy. The comparison results for Ni-P plated and heat-treated Ni-P plated specimen exhibit wear loss rate of 1/6 and 1/10 that of AZ91D magnesium alloy respectively. The seal pretreatment and pickling pretreatment can offer an excellent bonding between the Ni-P deposition and AZ91D substrate surface. The technology is employed to AZ91D magnesium alloy automobile parts and can provide high hardness and high wear-resistant. The hardness of the electroless Ni-P plated is relatively low compared to Ni-P plated heat treated specimens. The deposition speed of the Ni-P coating cause an impact on improvement of hardness maximum results obtained at 29 μm/h [16].

A. Araghi et al analysed the effect of Ni–P–B4C hybrid composite coating from an electroless plating bath containing sulfate nickel, sodium hypophosphate and suspended B_4C particles on the corrosion and wear resistance of an AZ91D, high aluminum cast magnesium alloy, was investigated. The pH value of the electroless bath is maintained upto 9 at a constant temperature 82°C. At the appropriate Ph value and temperature, B_4C particles were spread generally over the surface of AZ91D substrate in the hybrid composite coating. The Ni–P–B4C composite coatings had relatively excellent hardness (1200MPa) and wear resistance twice that of Ni–P electroless coatings. But the corrosion resistance properties Ni–P–B4C coated AZ91D substrate is not much superior compared to Ni–P coating [17].

Table 1: Coating Process Parameters

Coating Method	Significant Parameters
Plasma Electrolytic Oxidiation	DC voltage, Electrolytic bath, plating time, pH value, Temperature, stirring rate.
Electroless Plating	Electrolytic bath, plating time, pH value, Temperature, stirring rate.
Laser Surface Remelting	Laser type, incident laser power, scan speed, laser spot size, overlapped region and melted depth.
Thermal Spray	Gas ratio, shield gas flow rate, stand-off distance, carrier gas flow rate, feeding rate, compressed air pressure, and relative gun velocity.
Friction Stir Melting	Rotational speed, travel speed, plunge depth.
Physical Vapour Deposition	Working medium gas, target distance, gas pressure, DC bias, magnetron current and deposition time.

LASER MELTING TECHNIQUE

Laser composite coating is a coating technique of surface modification, in which, high intensity laser is allowed to focus on the material surface to melt. In which, the nanopowders reinforced in melt surface of the substrate is allowed for resolidification which results in well refined fine grain composite layer over the surface. The process parameters for LSR are laser type, incident laser power, scan speed, laser spot size, overlapped region and melted depth.

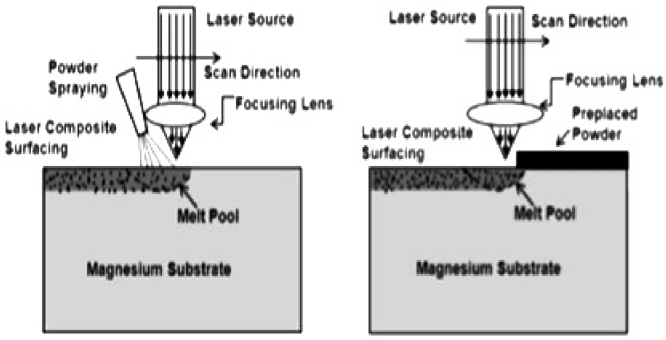

Figure 3: Schematic Illustration of LSR Process

Z. Zhang et al investigated the wear effects of CO_2 laser surface remelting on AZ91D magnesium alloy. Laser Surface Remelting parameters are output power (1400 w, 1600 w, and 1800 W), scanning speed (300 mm/min, 600 mm/min and 900 mm/ min) and laser beam diameter of 1.5 mm are varied to study their effects on tribological and mechanical property. The volume loss and microhardness are found at rotating speed 400 rpm, the sliding duration was 10 min and a load of 5 g, loading time of 10 s respectively. The LSR sample with the output power of 1800 W and at the scanning speed of 900 mm/min exhibited the highest microhardness and wear volume loss was reduced of all samples. As the scanning speed increased, the amount of β-Mg17Al12 was decreased, the dendrites were better refined. Therefore the microhardness increased with it. The wear resistance directly depended on the microhardness [18].

J. Dutta Majumdar et al attempted in reduction of wear loss of (MEZ) Mg alloy, by formation of composite layer on the surface, by incorporation of SiC nanoparticles by CO_2 laser. The process variables of the incident laser are power (P=1–4.5 kW), scan speed (v=100–400 mm/min) and powder feed rate (Fp=16–30 mg/s). This process is done at a high power of 10 kW and allowable angle of 50 degrees is set between the powder nozzle and the specimen. Argon gas is used, since it prevents oxidation of coating material and the substrate. Wear of the composite surfaced MEZ was tested using Pin-on-Disc wear testing machine against hardened steel disc with a 3 kg applied load and 300 rpm wheel speed. The average microhardness was found to decrease with increase in laser power, and it decreases with increasing scan

speed. The highest results are found at optimum parameters with a power 1 kW, scan speed 200 mm/min and powder feed rate 20 mg/s are microhardness 270 VHN and cumulative Wear 150µm. The presence of hard SiC particles improved wear resistance of the composite surfaced MEZ [19].

B. Mehrjou et al plasma sprayed the surface of AZ91 Mg alloy with WC–12 wt-% Co powder and was melted by pulsed Nd:YAG laser. The factors for the laser treatment are Pulse energy 18J, Pulse duration 9 ms, Scan speed 5mm s^{-1}, Frequency 13Hz and Overlap factor 50%. Laser treated layers showed much finer structure compared to that of the original base material with suitable distribution of WC particles. They found the results as, Microhardness was 3.5 times higher than that of the base material and the wear rate to less than half in the laser treated layer. Hence, they concluded that pre spray treatment before laser treatment makes the particle distribution excellent [20].

J. Dutta Majumdar et al laser surface alloyed AZ91 magnesium based alloy (Mg–9Al–0.9Zn) with nickel and compared the results with received AZ91 substrate. They conducted Laser surface alloying with continuous feeding of nickel powder particles with particle size from 25 to 50 µm under 10 kW continuous wave CO_2 laser. The wear resistance property of laser-surface-alloyed AZ91 was evaluated using a Pin-on Disc wear testing unit against an SiC-dispersed emery paper of 500 grits at an applied load of 1 kg at 300 rpm showed Loss in weight per unit area of 3.6mg mm^2 while the received material of 7.8mg mm^2. Dispersion of intermetallics of Mg and Ni (MgNi2) in a magnesium matrix with an improved Young’s modulus from 45GPa to 85 GPa [21].

B.J. Zheng et al laser cladded AZ91D Mg alloy surface with Al+SiC powders by pulse-laser (Nd–YAG). The particle size of aluminium and silicon carbide powder are 44µm and 40nm respectively, were mixed with SiC weight ratio of 10, 20, 30 and 40wt%. The laser cladding was performed at a wave length of 1064 nm, beam size 500 mm, focal point 3mm, scanning speed 0.5 mm/s, duration time 5ms, frequency 6 Hz, laser power density 700J/cm^2 and overlap 30%. The laser cladding showed very good bonding with the magnesium alloy substrate. Tribiological wear behaviour tests were conducted in pin-on-disc test apparatus with fixed speed of 3.14 m/s, steel disc hardness 600HV, pin length 25mm, pin diameter 6mm, applied load 10N, sliding distance 188–942m, sliding speed 3.14m/s and sliding time 10min. SiC particles of 30wt% shows the minimum wear volume loss for all consecutive wear time and microhardness of 160HV is obtained [22].

THERMAL SPRAYING TECHNIQUE

The basic principle of Thermal spraying technique is based on heating and melting a feed stock material powder, before accelerating it to a high velocity and then allowing the particles to strike the substrate surface. The particles allowed freely to re-solidified on the substrate. The coating is formed when millions of particles are deposited on top of each other. These particles are mechanical or metallurgical bonded to the substrate.

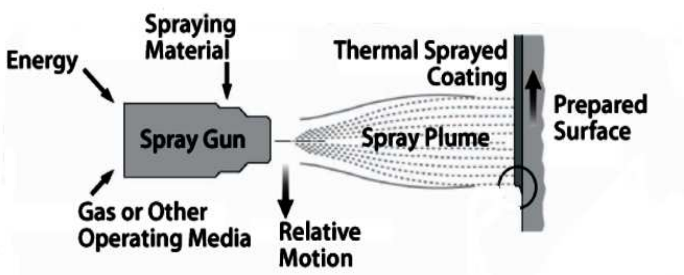

Figure 4: Schematic Illustration of Thermal Spray Process

P. Rodrigo et al generated Al and Al–SiC composites by oxyacetylene thermal spray coating another strategy for the improvement of the wear behavior of ZE41 substrate. Coatings with controlled reinforcement rate of up to 23 vol% were obtained by spraying mixtures containing aluminium powder with particle size 150µm up to 50vol% SiC particles of 52µm in size. The wear test was carried out with 10 N load, 8 mm diameter and 200 rpm for a total wear length of 150m. sprayed coatings reinforced with 12.3 vol.% SiCp show that 85% more wear resistance than uncoated ZE41 and 400% more than pure Al coatings. The volume percent of SiC increases the hardness of coated material also increases. Flame spraying provides better corrosion protection on ZE41 [23].

Lo´ Lopez et al have improved the wear performance of ZE41A magnesium alloy using coatings of aluminum reinforced with 10 wt% SiC particles deposited by high velocity oxygen-fuel (HVOF) technique. The parameters of the thermal spraying system have been optimized in order to maximize the SiC particles incorporation in the aluminium matrix of the coating, and to minimize the mechanical deterioration of the light alloy substrate. Composite coatings with thicknesses of 120 µm, reinforced with ∼10 wt% and with high adhesion to the substrate were achieved. The wear resistance of the substrates was increased and the wear rate decreased in two orders of magnitude, respect to that of the bare Mg-alloy after the optimization of the spraying parameters [24].

Maria Parco et al conducted HVOF spray coating on AZ91 and AE42 Mg alloy substrates using WC–12Co with particle size 20 µm. The experiment were conducted under the following conditions O_2/H_2 ratio 0.31, shield gas N2 300/min, stand-off distance 340mm, carrier gas N2 20/min, feeding rate 52g/min, compressed air pressure 5 bar, relative gun velocity is 600 mm/s. The micro-hardness of the coated AZ91 substrate is 88 HV at a depth of 240 µm and 71 HV at a depth of 740 µm. The high kinetic energy impact of WC–12Co particles hardens the Mg alloy substrate surface. The adhesion strength of the coated AE42 Mg alloy substrate is improved. The HVOF spray coated AE42 and AZ91 Mg alloys have enriched micro hardness and adhesion strength which enhance the wear resistance of coated Mg alloys [25].

PHYSICAL VAPOUR DEPOSITION TECHNIQUE (PVD)

PVD process is a material coating technique which includes Arc evaporation, Sputtering, Ion plating, and Enhanced sputtering. In this process, the material to be coated is evaporated by ions bombardment with sputtering process. Simultaneously, a reactive gas like nitrogen or a carbon gases is added forms a metal vapour compound, which is deposited on the substrate to give adherent coating. By rotating the parts about various axes at a constant speed, uniform coating thickness can be achieved.

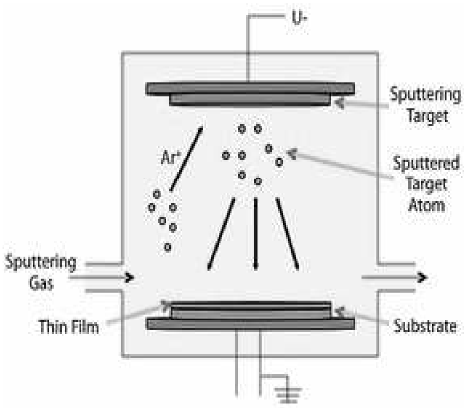

Figure 5: Schematic Illustration of PVD Process

Hikmet Altun and Sadri Sen studied the influence of the physical vapour deposition (PVD) on AZ91 Mg alloy coated with AlN/TiN and wear behaviour of the alloys was examined. Inorder to achieve good adhesive bonding, DC magnetron sputtering method uses two target (Al target, a Ti target), working medium gas nitrogen gas, target distance 90 mm, pressure 0.4 Pa, DC bias −60 V, magnetron current 5 A and deposition time 120 min (60 min AlN+60 min TiN) for AlN/TiN coating. The reciprocating wear tests conditions are normal Al_2O_3 ball, load 150 gf, ball diameter 10 mm, sliding speed 0.02 m/s and sliding distance 40m. It was determined that the wear resistance of the magnesium alloys can be increased upto 0.4×10^{-3} mm^3/Nm and surface hardness increased about 70% (i.e 103 HV) for AlN/TiN coating. The only defect is that small structural defects, which could arise from the coating process or substrate were observed in the coating layers [26].

Tomasz Tański produced a triple layer coatings deposition on Mg alloy AZ61 substrate by physical vapour deposition and Plasma Assisted Chemical Vapour Deposition method. The triple layers are metallic layer, gradient layer and ceramic layer was deposited. Varying the PVD coating parameters cathodes diameter, base chamber pressure, target current, process temperature, argon ion pressure, time duration. Adhesion of the coatings is improved by deposition of Ti interlayer. The wear tests were performed at room temperature with the following test conditions such as load 5 N, rotation of disk 200 turns/min, wear radius of 2.5 mm, shift rate of 0.05 m/s. The DLC coatings reveal the better wear resistance compared to other coating [27].

J. SMOLIK et al compared the tribological and corrosion properties of multilayer layer ($MgAl_{itermetalic}$ layer and PVD coating) encrusted on Mg alloy AZ91 by two different configuration surface coating technology. In the first combination of "$MgAl_{itermetalic}$ / PVD coating" composite layer follows in the ascending flow as magnetron sputtering (MS), arc evaporation (AE) and vacuum heating methods. The second type of "$MgAl_{itermetalic}$ / PVD coating" layer was prepared using a hybrid technology with a di□usion treatment process in Al-powder and the electron beam evaporation (EB) method each process is followed on after the other. The ball cratering method is performed for wear test with ball bearing steel ŁH 15, ball diameter 25.4 mm, applied load 0.4 N and the rotating speed 400 rpm, sliding distance to 500 m, wetting liquid ethyl alcohol and liquid fed rate of 50 drops/min. The microstructure composite hybrid layer show bubble formation lead to decrement in wear and corrosion resistance. "$MgAl_{itermetallic}$ / Al2O3" composite layer show excellent wear resistance of $1.2\text{x}10^{-16}$ m^3/N-m [28].

Guosong Wu et al presented AZ31 magnesium alloy was coated by a composite coating, diamond-like carbon, aluminium nitride and aluminium using PVD techniques. The hybrid composite coating of Al, AlN and DLC was done by sputtering current 2 A, Ar flux 40 sccm, and time of deposition 30 min and using argon, nitrogen and C_2H_2 as flux with 40sccm for Al, AlN and DLC coatings respectively. The corresponding chamber temperatures and chamber pressures of Al, AlN and DLC were 35 ^{0}C and 2.2×10^{-3} Torr, 35 ^{0}C and 4.1×10^{-3} Torr, 80 ^{0}C and 1.2×10^{-3} Torr. The surface hardness and wear resistance was measured by using Nano-indenter and a rotary ball-on-disk tribometer respectively. The surface hardness of the DLC/AlN/Al coating on magnesium alloy was highly improved, and its friction coefficient under dry friction condition was reduced from 0.36 to 0.10. The average wear track width of uncoated AZ31 was nearly 576.8 µm, and the coated AZ31 was 92.5 µm, which shows the evidence for the enhancement in wear resistance of AZ31 magnesium alloy with high surface hardness and low coefficient of friction [29].

Y. Mao et al prepared composite coating (PVD carbon coating deposited on electroless plating nickel interlayer) to protect GW83 magnesium alloys against wear. wear tracks were observed for Magnesium alloy GW83 is coated with

nickel coating, carbon coating and Ni + C composite coating at a rotational velocity of 637 rpm for 8000 s, and the applied load was 2 N. The Ni + C composite coating could effectively improve the wear resistance of the GW83 magnesium alloy as a result of the high hardness, and the mechanical support show the carbon coating has good adhesion with the Ni interlayer in Ni + C composite coating of the Ni interlayer [30].

FRICTION STIR PROCESSING (FSP)

Friction stir processing (FSP) is a technique emerged to modify the surface properties of metallic sheets and plates. In this process, a blend edge pin end cylindrical rotating toolwhich is trusted along the traverse length by applying a suitable load on the substrate is used. The surface of the substrate suffers intense plastic deformation and dynamic recrystallization is initiated at localized stir zone, which lead to deposition of coating material with adhesive bonding strength.

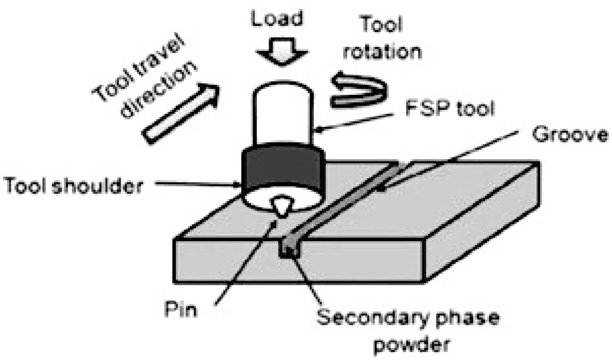

Figure 6: Schematic Illustration of FSP

D. Ahmadkhaniha et al, coated Composite layers containing 0.8 %vol nano-sized (50 nm) Al_2O_3 nanoparticles were produced on AZ91 magnesium alloy by friction stir processing (FSP). The rotational speed of 800 rpm and the travel speed of 40 mm/min were the optimum parameters of FSP for achieving a suitable composite layer, with the highest hardness and wear resistance among the treated layers. The treated layers increased the microhardness by almost more than 30% and mass loss to less than half. High hardness and uniform dispersion of the Al2O3 particles decreases the direct load in wear condition. Changing the direction of rotation of the tool results in higher distribution of particles uniformly [31].

H. S. Arora et al fabricated AZ31 and TiC based surface nanocomposite on magnesium AZ31 by friction stir processing. Particle size TiC was about 40 µm is taken as the reinforcement powder. FSP is carried out using vertical milling machine (5 H.P) (CNC) with the help of FSP tool rotational speed of 800 rpm, linear speed of 40 mm/min and plunge depth of 0.3 mm to create uniform distribution of nano particles over the material surface. Dry sliding wear tests using Pin-on-disc configuration at 5KN and 20 KN normal loads, sliding velocity 1 m/s, sliding distance 1.5 Km. Compared to other FSP conditions Single pass FSP with TiC reinforcement and under surface cooling using coolant at -20° C show outstanding hardness and wear resistance Tool rotational speed has the highest influence on variation of hardness of the material [32].

Asadi et al studied Micro hardness and wear of AZ91 producing a composite layer using SiC particles of 5 µm by Friction Stir Process pass, at the rotational speeds and traverse speeds of 900rpm and 63mm/min, respectively. The micro hardness of the layer is inversely proportional rotational speed and the grain size is directly proportional in rotational speed. Increasing traverse speed and the number of passes decreases grains size, which improves the hardness value [33].

CONCLUSIONS

This present article provides a comprehensive review of Multilayer and composite coatings of various combinations and discussions. The relevant properties and preparation methods for various techniques are also summarized. The properties can be modified through selecting coating materials and processing methods. It was observed that wear resistance of substrates improved by coating with incorporation of nanoparticles. In order to improve tribological properties, it is suggested for future investigations. Keeping in mind cost, simplicity and safety factors, the next phase in the development of new technique which reduces the wear loss in magnesium and magnesium alloys, will lead to a better application in various fields.

- The critical wear loss rate was found lowest sliding speed, and when the sliding velocity increases, wear loss rate is reduced.
- Based on Archad relation, increment of hardness decreases the wear rate.
- Increment of both applied load and sliding velocity decreases the specific wear rate in all cases.
- The wear resistance of the coated material does not get higher results with increasing the particle content reinforced. The increase of sliding distance causes additional wear loss at a constant rate. If the applied load is high, it induces extremely high wear rate on specimens. The reinforcing particles with sharp edges are more effortlessly pulled out and machined away from the composites surface, with high particles content.
- Wear resistance of composite coated material does not improve at all times with increasing of nanoparticles reinforcement volume fraction.
- Wear behaviours are dependent on sample materials, counterface materials and its surface finish as well as testing conditions including the applied load, sliding speed and test environments.
- Reinforcement of a particle with regards to its size is inversely proportional to relationship with wear rate.

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